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TRADITIONAL HOUSING DESIGNS */

Prepared by

UNITED NATIONS CENTRE FOR
HUMAN SETTLEMENTS

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INTRODUCTION

Owing to the appalling housing situation in the world today, the poor and disadvantaged continue to exist in spite of the fact that governments have realised that there is a crisis in human settlements, leading to extremely unhealthy conditions in poor rural settlements as well as in slums and squatter areas. The housing shortages for especially the lower income population tend to increase every year and the building materials and construction industries cannot cope with the demand.

According to the latest projections, the world's population, currently estimated to be approximately 4,842 million people, will grow to 6.1 billion in the year 2000 and to 8.177 billion in 2025. Estimates also indicate that there will be more people in the poor countries of the world, and this population will live in overcrowded conditions and in higher concentrations than ever before. During the last two decades of this century, an estimated 1.1 billion people will have been added to the already teeming urban centres of the developing world. In most parts of Latin America, Asia and Africa, urban growth up to the end of the century will be equal to or in excess of the current levels, showing greater concentrations of people in urban centres and a rapid increase in the number of large cities in the developing countries. The most current urbanization forecasts estimate that by the year 2000 the number of cities in the Third World with more than 1 million inhabitants will approach 300 and will have a combined population of more than 1 billion. Moreover, the urbanization process in developing countries is taking place at a much lower per capita income level than in the developed countries. This means that decision-makers and planners in developing countries are faced with more financial constraints than those in developed countries at a time when a serious housing deficit is created by an increasing number of urban dwellers.

Building materials are the most important input to the construction sector. Surveys in a number of developing countries show that the intermediate consumption of materials and supplies range from 37 per cent to 55 per cent of the total value of construction output. Thus, the building materials industry constitutes a critical prerequisite to the development of construction activities and of development in general. Experience in developing countries over the last few decades has shown that the lack of adequate development of this sector can lead to considerable delays in the implementation of development projects. Moreover, foreign exchange constraints, owing to high foreign indebtedness and slack exports, impose severe external limitations to the development prospects of a great number of developing countries. In this context, owing to its potential for import substitution, and its role in development, this sector constitutes a priority target for any national policy aimed at satisfying the needs of the population and decreasing import dependency. The construction sector in a majority of countries is not using available resources optimally. Appropriate measures should be adopted to improve overall efficiency and productivity in the sector, especially in the development of locally produced building materials and components.

Timber is one of the locally available building materials in many countries in the world. However, there is a great lack of knowledge in technologies that use wood as a building material. The lack of information and the influence of technologies implanted without proper adaptation from industrialized countries have not been helpful in the use of proper designs and the treatment of timber as a material that could serve low-cost building. In many developing countries which possess tropical timbers, the housing situation can be ameliorated by the use of timber and its products in housing. However, one factor that prevents the extensive use of tropical forests is the wide diversity of species. Many secondary species have been ignored as building materials, although they are suitable to be used for this purpose. Poorly finished unseasoned, untreated

and ungraded products hinder the use of timber as a building material. Proper treatment and design can improve its resistance to fire, water, fungi and termites.

I. TIMBER FOR HOUSING

Although the general decline in the use of wood per dwelling unit can be attributed to many factors, there is little doubt that in the final analysis only the most rational application of wood in building - having regard both to technical suitability and to competitiveness in cost - will make worthwhile contributions to a solution to the problem. The impact of urban planning considerations and, in particular, of residential densities and site coverage allowances on the use of wood construction for low-cost housing can be far-reaching. In many parts of the world, where forest products are abundant, timber housing has been and remains today a living tradition. It was developed initially as a craft-based method of construction for rural housing. Its subsequent development for urban housing is still carried out in the main by conventional techniques, and even the most industrialized wooden house systems cater mostly for detached single family houses and to a limited extent for low-rise multi-dwelling houses.

Height of Residential Buildings and its effect on the use of wood in elements of structure

Extensive use of wood with safety and economy dictates low and medium-rise housing. Building codes, with fire risk in mind, vary in the severity of their restrictions on the use of wood for residential construction. Almost invariably, however, limitations increase with the height of buildings. Other functional considerations and long experience also tend to favour low construction. A point in relation to house design which needs to be borne in mind is the inflexibility of multifamily housing with regard to future extensions. Single-family houses can be expanded by an additional storey or rear extension, even if houses are attached in rows or in cluster arrangements. With the prevailing large families in developing countries, combined with small incomes, such flexibility will inevitably commend itself to planners. Wood construction is ideally suited to permit future extensions at little or no extra initial cost. In medium-density development, with row or cluster housing, separating walls of non-wood materials or preferably, of wood-wool cement slabs, probably provide the simplest solution.

House plans and planning principles

The planning of dwelling, both as relates to the general configuration and the internal arrangement of rooms and services, has an important bearing on the economy of building, whatever materials are used. Climate and mode of living are the prime factors, but the type of structure and the characteristics and limitations imposed by available building materials also play their part. There is little factual information about the comparative economy of different house plans offering similar accommodation. Nevertheless, it is possible to indicate a few guidelines which are of particular relevance to the economic use of timber.

As a general rule, rectangular plans are the most economical, particularly for the use of wood and wood-based panels, which are generally rectilinear and rectangular. Such plans lend themselves best to standardization of elements and components, and the dimensional coordination of plans with available materials can do much to avoid unnecessary labour and waste. Encouragement of the adoption of standards in general and modular standards in particular can be given by their enforcement in the public sector.

In detached houses, plans nearest to the square in overall shape provide most space for minimum enclosure, but this consideration is secondary to that of using available standard sections and lengths and the plan shapes dictated by them. In row houses, narrow frontages are usually more economical in general development costs and in building costs (e.g. reduction of spans for wood members in floors and roofs when spanning between party walls). In general, projections from the plain rectangle add to cost and should be avoided unless dictated by climatic or similar considerations. L-shape plans may be justified in attached houses arranged in patio formation, but the additional hips and valleys (in the case of pitched roofs) add to cost. Internally, wide spans should be avoided wherever possible by making partitions load-bearing (at little or no extra cost). In two-storey houses, partitions should be superimposed wherever possible to avoid high bending moments on the intermediate floor joists.

In many countries, government ministries or agencies concerned with housing have not only laid down minimum standards of accommodation and equipment for low-cost housing, but have issued many standard plans for adoption by builders, housing associations and individuals. The best solutions in each country or region are likely to be found in the adaptation of traditional house plans to suit the requirements of modern materials and services. Prototype plans should be carefully prepared with an eye to the limitations imposed by available forest products and production techniques. The involvement of experts from the forest and building industries at an early stage is therefore essential.

Dwellings have to satisfy many diverse requirements according to climate, living habits, and standards which can be afforded. Some of these requirements have little or no bearing on methods of construction and materials, but others affect them profoundly. Durability and maintenance considerations affect especially the choice and treatment of wood materials. Other functional requirements can be met with ease in wood construction, often by the addition of other materials which can be readily tied or fixed to the structure.

Design procedures

Where an extensive use of wood in a housing project is desired, the designer and investor should consider the choice of house types and arrangement of site layout with an eye to possible inherent or statutory limitations, and modify the concepts or obtain necessary relaxations. The preliminary choice of structural forms will be followed by the systematic review of functional requirements, and the way to deal with them before proceeding to detailed structural design. As to the method of structural design, there are three recognized procedures, and some codes will accept any of them as valid (a) the conventional (traditional or rule-of-thumb) (b) structural analysis and (c) prototype testing.

As a rule, these procedures are economical in materials in the order listed. They each have their advantages and limitations. The first method, based on past experience and intuition, takes little account of technological advances and improvements in quality of materials. Its systems often contain structurally redundant parts These may be oversized, due to inefficient jointing, or ignorance of the strength properties of the materials used. Cutting down on member sizes or traditionally accepted minima in jointing methods (e.g., by speculative builders) may result in inadequate structures.

The second method is based on the application to design of the fundamental laws of mechanics and on empirical knowledge of the behaviour of materials and structures under diverse loading conditions. The resistance of the structure and the applied loadings are then correlated to provide safe buildings. A prerequisite of the analytical method is a knowledge of the strength properties of the materials to be used and of the loadings to be assumed. Neither one nor the other, however, are easily evaluated constants, but are variables over wide ranges. Safety cannot be regarded as a simple factor by which all stresses are reduced or all loadings increased, but must take into account the type of risk involved and an acceptable probability of failure which is statistically determinable. Design codes generally make inadequate allowance for load-sharing between members and tend to be conservative in some other important respects as well. There is great need for an international pooling of experience and resources to obtain more economical design criteria everywhere.

Prototype testing of components or elements also assume a knowledge of loading conditions which have to be simulated with adequate safety factors. A consistency in quality of materials and workmanship in repetitions of the prototypes tested is also assumed. Repeat tests on a number of samples are also required in some codes.

II. FACTORS AFFECTING STRUCTURAL EFFICIENCY

Three main considerations govern the efficiency of wooden structures (a) the strength properties of the materials (b) the means of connection between members and parts (c) the forms selected (for member components or complete building structures). During the past few decades considerable progress has been made in many countries in establishing standards of sizes and qualities for sawnwood and various wood-based panel products, often including stress grades based on the limitation of strength-reducing characteristics (such as knots, wane, slope of grain, etc.). Such standards are a prerequisite both for analytical design and for prototype testing. Grade stresses have been laid down not only for practically all available softwood species but for many hardwoods as well. In some countries wood species of similar strength characteristics are assigned group working stresses in order to simplify analytical design procedure. This method would appear to have particular merit in the possible exploitation of mixed secondary species from tropical forests, whose strength classification into groups could be most readily determined by density considerations. The assignment of strength and elasticity values based on a limited range of preferred numbers has been widely advocated and is already applied in Malaysia and East Africa.

Grade stresses assigned to visually graded softwoods generally err on the side of caution by the nature of the methodology employed in establishing them. Electro mechanical grading, already introduced on a limited scale in several countries, including Australia, where it has been used for grading hardwoods, is likely to increase the strength rating of timbers of all species to which it is applied.

Whatever grading methods are adopted, there appears to be little doubt that a great many, species in tropical forests not at present exploited commercially have ample strength properties for structural uses in housing. P.A. Campbell [1] recommends a simple performance specification which divides sawnwoods into three grades: structural, constructional (but nonload-bearing) and joinery quality. By lowering the standard of requirement, especially for the two former grades, he estimates that a saving of 15 per cent in cost has been achieved in East African

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[1] Campbell, P.A. Performance specifications for the quality control of timber for housing in developing countries. WCH/71/6/2.

countries where such a specification has been adopted. The simplicity of these grading rules contrasts with the greater sophistication and complexity of the standards which are now obtained in highly industrialized countries, in particular in North America.

The development of efficient means of connections has been a major factor in the advance of timber engineering in the past few decades, and has permitted progressive reductions in sizes of structure/components. J.D. Boyd [2/] gives a comprehensive review of available methods and the factors affecting them and influencing their choice. Particular attention is given to the problems of jointing relatively dense hardwoods and means of overcoming them. Nailing is the most common solution for jointing timbers in housing in the developing countries - as it is in the industrialized regions.

III. NON-STRUCTURAL COMPONENTS AND USES

The design of non-structural components and parts is governed by various functional requirements relevant to the particular end use, as well as by available materials and methods of production. Functional requirements affect in particular surfacing uses such as floors, wall claddings, internal linings of walls, partitions and ceilings. Economy in design dictates the use of single parts to perform dual or multiple functions. This is particularly true of finish surfaces in wood or wood-based panels, which can usually be exploited structurally in addition to their primary functions.

Joinery and wood trim constitute an important group of wood uses. Wooden doors, windows, shutters, cabinets, shelving, skirting, etc., are widely used in housing even in countries with scarce forest resources. The designs of some of these items are largely influenced by traditons and climatic conditions. Increasing attention is being given in many countries to design adjustment according to the needs of rationalized production techniques. As with structural components, the general trend in the design of joinery items is toward economy in material content - largely achieved by the use of wood-based panels, and simplification of details of construction to reduce the number of necessary operations.

2/ Boyd, J.D. Problems associated with the use of wood in construction. WCH/71/4a/2

In modern design, particularly of low-cost housing, many traditional wood trim items such as skirtings, picture rails, architraves, barge boards, eaves, fascias and soffits are reduced to minimal dimensions and often completely eliminated. However, details must be carefully studied to avoid detrimental effects on function or appearance.

Regarding ancillary uses, mention must be made of formwork and scaffolding for which sawnwood, poles and panel products are used on a large scale. Careful structural design and selection of material are essential to guarantee both economy in material and the safety of operatives. Multiple use and reduction of waste in scattering can best be achieved by panelization, which in turn dictates a measure of dimentional standardization in building.

IV. PRODUCTION AND ERECTION TECHNIQUES

For the construction of houses, wood and wood-based panel products enjoy a number of advantages over most other materials from the point of view of production and erection techniques. They are light and strong, easy to work, assemble and fix with simple hand tools, and also relatively easy to transport and erect in large sections without the use of costly equipment. This extreme flexibility has enabled a wide variety of production and erection techniques to be developed, attuned to the technological levels of different sectors of the building and wood-working industries which co-exist in most countries, and to the characteristics of the housing markets in which they operate. The methods range from on-site preparation of materials and stick-by-stick assembly of the houses to the most advanced prefabrication and shop-finishing of complete dwelling units, or sections of dwellings, and their subsequent transport and placing on prepared foundations. Between these two extremes there are many intermediate stages, each with a different distribution of labour and skills between factory and site. The adoption of one method or another in a particular set of circumstances depends not only on technical feasibility but to an even greater extent on economic justification.

V. COST COMPARISONS BETWEEN TIMBER-FRAME AND OTHER HOUSES

Cost comparisons between houses built with different materials and techniques are not easy to establish for a number of reasons, which may be grouped as follows:

(a) It is difficult to equate comparability of performance and to assess the value to be placed, e.g., on better insulation, finish, durability, appearance, etc.;

(b) The wide range of variations in site labour requirements and building costs, even for the same method of construction, owing to differences in plan, house size, details of construction, site and weather conditions, size of contract and, in particular, efficiency of management and labour, in which specialization and continuity play a large role.

For these reasons (particularly those in the second group), estimates of cost based on designs or on prototype houses, or even on small numbers of houses of new types, can be misleading.

A study made in Rangoon, Burma, has shown comparative costs of timber houses constructed as alternatives of high-cost type of dwellings made of bricks, cement, and asbestos-cement roofing sheets. The low-cost timber houses constructed for this project consist of four basic timber frames assembled at a central workshop before all materials are transported to the site. At the site, the frames are assembled using bolts and nuts. This way semi-prefabrication techniques reduce the labour requirement to about 70 per cent of the traditional way of construction, as well as reducing the construction time. The cost per unit area of this system ranges from 40-60 kyats/sq. ft. as compared to 180-220 kyats/sq. ft. of masonry structures with load bearing walls; 200 - 280 kyats/sq. ft. of reinforced concrete structures with brick filling walls, and 150 - 200 kyats/ sq. ft. of timber frame structures with brick filling walls. Only bamboo structures or mixed timber and bamboo structures, with a price range from 6 to 10 kyats/sq. ft., can compete with timber frame structures with timber walling (see table).

Table. Cost per Unit Floor Area of Different Types of Structures in Rangoon, and Advantages and Disadvantages

No.	Type of Structure	Cost per Unit Area Kyats/sq. ft.	Advantages and Disadvantages
1.	Masonry structures with load bearing walls	180 - 220	Since the walls must be thick enough to carry loads, the walls absorb heat in day time and transmit it in the evening. Least earthquake resistant compared to other structures.
2.	Reinforced concrete frame structures with brick filling walls	200 - 280	Better thermal behaviour, good earthquake resistance, most expensive of all types.
3.	Timber frame structures with brick filling walls (Brick nogging structures)	150 - 200	Better thermal behaviour, good earthquake resistance. The durability can only be that of the timber.
4.	Timber frame structures with timber walling	40 - 60	Good thermal behaviour, good earthquake resistance. Shorter life compared to masonry structures, about 80 years, flammable:
5.	Bamboo structures or mixed timber and bamboo structures	6 - 10	Good thermal behavior, good earthquake resistance. Shortest life and highly flammable.

Source: Rangoon City and Regional Development Project, TCD, UNCHS (Habitat), 1985.

Component production and cost

Standardization and mass production of individual joinery and structural components lead to cost reduction through refined design with consequent economy in materials (e.g., through glueing and use of sheet materials in flush door production, or pressing inserted tooth plates in trussed rafter manufacture), and through reduction of albour requirements by mechanization and division of operations. Despite the progress achieved -particularly in industrialized countries- further rationalization in the design of components and their standardization can still be achieved to reduce costs further.

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ON A MANUAL FOR INTRODUCING TIMBER ENGINEERING DESIGN IN DEVELOPING COUNTRIES*

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1. SCOPE

The purpose of the proposed manual is to introduce an instant design capabilty in timber engineering to a developing country that previously had none. It will be assumed that the country has engineers that have been trained in the basic concepts of structural engineering, but who have no prior knowledge of timber as a structural material.

The four essential Parts of the manual will be the following:

Part 1. Terms and Definitions
Part 2. Classification Procedures
Part 3. Design Code
Part 4. Worked examples

In addition to the above, there are three others sets of information that may be required, depending on the technology base of the country intending to engage in timber engineering.

For countries with no previous experience in timber construction, the following Parts will be required,

Part 5. Selection and Specification of Timber
Part 6. Detailing of timber structures
Part 7. Construction
Part 8. Maintenance

For countries with a limited background in structural design technology the following Parts may be required,

Part 9. Structural analysis
Part 10. Minimum design loads

Finally the following two Parts could be added to stretch the design capability of the manual,

Part 11. Composite structures
Part 12. High hazard loads

In addition to the above, it is desirable that a commentary be prepared, explaining the technical background of the various Parts of the manual, and stating the structural performance expected of designs that comply with the recommendations.

2. CONSTRUCTION OF THE MANUAL

The overriding consideration in drafting the various Parts of the manual should be that they be readily understood. As timber structures by their very nature have complex characteristics, the necessary simplifications will generally lead to conservatism in design. However once timber engineering (and the necessary industry infrastructure to support it) have been introduced into a country, the technology can be expanded through an evolutionary process towards that of developed countries.

It is proposed that the first draft of the manual be based on existing Australian standards. This is suggested for two reasons. First, these standards have been used as a basis for UNIDO projects in the past; thus their value has been proven, UNIDO field officers are familiar with the system and so they could be used to produce useable manuals within a short period of time. The second and an important reason is that the Australian standards have a format that is suitable to the range of species and the technology infrastructure that is available in most developing countries. In this context it is of interest to note that the timber of more than 1000 species that grow in developing countries have been formally classified into structural groups according to the Australian system (Berni *et al.*, 1979; Bolza and Keating, 1972; Keating and Bolza, 1982).

A suggestion for future modifications of this manual is that once suitable ISO standards have been developed and accepted, the manual be modified to mesh in with these standards; this will facilitate the evolution to more sophisticated technology for countries that have successfully introduced timber engineering. Of course, it goes without saying that the manual should line up with any other documents developed

by UNIDO, such as for example UNIDO recommendations for visual grading rules.

The design procedure proposed for the first version of the manual is the 'working stress' format rather than the more modern 'limit states' format, as the former would probably be more familiar to engineers in developing countries. Similarly, the language used will be English and the units used the international SI units; it is envisaged that eventually several versions of the manual will be produced in a combination of language and units to suit the needs of various developing countries.

3. COMMENTARY ON PARTS 1-12

3.1 Part 1. Terms and Definitions

This Part will contain a definition of terms used in the manual that may not be familiar to an engineer inexperienced in timber engineering. For a more comprehensive glossary reference will be made to the standard AS 01-1964 (Standards Association of Australia, 1964)

3.2 Part 2. Classification Procedures

The classification procedures used in Part 2 will be based on simplifications of those given in the documents AS 2082, AS 2099, MP45, AS 1720 (Standards Association of Australia, 1977a; 1977b; 1979 and 1982). As indicated earlier, this classification system has already been applied to the timber of more than 1000 species that grow in developing countries.

3.3 Part 3. Timber Engineering Design Code

This will be based on a simplification of AS 1720-1975 (Standards Association of Australia, 1982). To ensure simplicity, the contents of Part 3 will be limited to considerations of rectangular sawn timber members, pole timbers, nailed joints and bolted joints.

3.4 Part 4. Worked Examples

Examples will be chosen to illustrate the design Rules of Part 3.

3.5 Part 5. Selection and Specification of Timber

This Part should include consideration of matters related to timber durability, availability, sizes and moisture content at time of delivery. It could also contain information on methods to assure the quality of purchased products.

3.6 Part 6. Detailing of Timber Structures

This should include detailing of standard joints and also methods of mitigating the adverse effects of shrinkage in green timber.

3.7 Part 7. Construction

This Part would include recommendations related to avoiding adverse notching, to the fabrication of joints, the avoidance of buckling during erection, good practices for on-site storage of materials and acceptable tolerances in fabrication and erection.

3.8 Part 8. Maintenance

This Part would include description of techniques for coping with the effects of construction with green timber (for example the retightening of nuts on bolts), the inspection of structures to detect incipient or existing decay and remedial measures for any observed structural distress.

3.9 Part 9. Structural Analysis

This Part would include a set of equations for the stresses and deformations of simple structural members and systems; it would also include formulae for the conversion of structural parameters from one

set of units to another.

3.10 Part 10. Minimum Design Loads

This would be a simplified set of loads based on the document AS 1170 (Standards Association of Australia, 1975; 1981). These will be essentially wind loads and floor and roof live loads; they will be suitable for buildings that are not subjected to severe natural hazards such as hurricanes, earthquakes and floods.

3.11 Part 11. Composite Structures

Examples of useful composite construction would be spaced columns, boxed beams, I-beams, trusses, glued laminated timber and nailed laminated timber construction.

3.12 Part 12. High Hazard Loads

The intent of this part would be to provide simple methods for estimating high hazard loads such as earthquakes, hurricanes and floods. Advice will also be given in simple construction techniques for mitigating the effects of these hazards.

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TIMBER PRESERVATION STANDARDS *

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Introductory Note

For this meeting the discussion is confined to considerations of conditions which obtain in developing countries and to preservatives most relevant to construction. This paper is also intended to be a lead to the group discussion on drafting a general code for use in developing countries.

There are two main problem areas in gaining widespread use and acceptance of timber preservation. The first is the technical problem of formulating satisfactory and realistic preservation standards for the various local hazards and timber species. The second much more difficult problem is ensuring that these and no other preservatives and methods are used. The two must go together and for preservation to be generally acceptable and satisfactory there must be enforceable and enforced regulations against the offering of timber as "treated" or "preservatised" and against the sale of non-approved chemicals as timber preservatives. Simultaneously, educational and promotional campaigns must be instituted and maintained at all levels - specifying professions, the timber and building industry down to the general public.

Specifications

In a developing country anxious to utilise more of its timber resource, one may find:

- a government owned railway sleeper and/or utility treating plant;
- one or more non-government pressure or diffusion plants;
- a range of Na-PCP or copper naphthenate solutions on sale as "wood preservative".

In formulating preservation standards and associated regulations, it is probably wisest to concentrate on the second, leave the first alone, and try and educate and regulate the third off the market. Government owned sleeper and pole plants are probably being operated fairly well and in any case theirs is a specialized product whose performance is unlikely to greatly affect other areas of timber construction.

Also such a body is unlikely to take kindly to being roped in to the construction industry with which it has little in common. However, if it is interested and enthusiastic over promoting preservation, well and good.

On the sale of penta etc. solutions, it may be argued that anything is better than nothing, but the situation should be watched and at the first indications of resistance to the purchase of properly treated timber on the grounds of its price compared with brush-on solutions, steps should be taken to remove them from the market in the public interst.

Scope of Specification

It is suggested that specifications should cover only waterborne preservatives of the CCA and boron types. These are capable of covering the whole range of preservation requirements for construction. Possibly insecticidal glueline treatment for plywood could be included (dieldrin, chlordane).

Other treatments are not included since in the opinion of the writer they have little relevance to the general requirements of a developing country.

Creosote and PCP in heavy fuel oil require expensive plant for application and their end uses are limited to sleepers, utility poles etc. If a creosote plant exists, then its operation is most likely covered by remarks in the above. Organic biocides in light oil are not very effective if applied only by dipping, although their use as a water repellent on already impregnated joinery is to be commended. With vacuum application of such preservatives (e.g. "Vascol") plant expense again becomes high, and penetration is limited unless a very light solvent is used in which case a major fire hazard exists at the plant.

One other process which might be considered is creosoting by the hot and cold bath process. This meets most of the requirements of technology in a developing country and in fact was recently recommended by the writer for installation in Madagascar as part of UNIDO prefabricated bridge process. (See Appendix 1).

The writer considers that the Preservation Treatment specifications of the Fiji Department of Forestry are a good model for use in other developing countries. They cover in sufficient detail the basic requirements for vacuum-pressure and diffusion treatments of a range of tropical and softwoods without being over-prolix and detailed.

The Fijian specifications will obviously require certain amendments. The lists of Fijian timbers in e.g. Section 3 and Section 5 would have to be replaced by appropriate local species. Some of the explanatory material might be considered as rather brief and the writer considers that the process specification for Bethel (Full Cell) vacuum-pressure treatment appended to the Papua New Guinea specifications should be included.

Another shortcoming is that the Fijian specification makes no mention of diffusion treatment with straight boron salts, e.g. borax-boric acid, "Timbor", etc. Boron does not give good protection against termites, at least not in reasonably attainable concentrations.

However, in core concentrations of 0.2% boric acid equivalent (BAE) it gives excellent protection against lyctid attack and at 0.1% BAE against anobid attack. The BFCA formulations in the Fijian specifications do give good termite protection due to their arsenic content and a comparison is given by Tamblyn et al (1) * which shows that the BFCA salts are comparable to CCA salts in this respect, and from 3 to 10 times as effective as borax-boric acid. However, C. R. Levy firmly believes in the deterrent effect of boron provided alternative wood is available (pers. comm), since termites will sometimes eat treated wood rather than starve.

The writer therefore believes that a straight boron salt process should also be included. Because of the large number of degrees of freedom in the operating parameters it is not possible to write a general process specification for boron diffusion but a few selected process specifications are given in the NZTPA Specification (2)* sections P6, P7 and P8 (Appendix 1). It should be made clear in a model specification that the process is not limited to these methods. For example in Sri Lanka effective boron treatment is achieved by overnight spraying of open stacked timber with a fairly weak solution followed by diffusion achieved in a covered fillet stack of rubber wood (Hevea Brasiliensis). Control

*See page 4

of wind velocity through the stacks is done by letting down rattan blinds. In this process the satisfactory diffusion is achieved through the high ambient temperatures and humidity and low wind velocity peculiar to the locality, and would not be possible in any other climate.

Regulations

Some form of enforceable regulations are required to ensure compliance with the specifications and to deter and if necessary punish unscrupulous operators. It is important that the regulations should be separate from the specifications. Legal and technical documents do not mix satisfactorily and making specifications part of a regulation inhibits technical progress.

The form and authority for these regulations must be a matter for local concern and no full model can usefully be offered. The NZ regulations are appended as an indication of what might be covered. The writer considers that the major points for consideration in these regulations are Clauses 2, 3(1), 3(3), 3(4), 8, 9(1), 9(2), 9(3), 10, 12 and 13(2). These form the core of the regulations and give them its teeth. It is interesting that although the regulations are administered in the NZ Forest Service they are actually made under the Board of Trade Act, and their enforcement then becomes a matter of commercial law.

References

1. Tamblyn, N., S.J. Colwell and G.N. Vickers, 1968, "Preservative Treatment of Tropical Building Timbers by a Dip-Diffusion Process", Ninth British Commonwealth Forestry Conference, Rentosol, London.

2. Timber Preservation Authority - Specifications N.Z. Forest Service, Private Bag, Wellington.

APPENDIX 1 *

Hot and Cold Bath Process—P1

The timber to be treated is placed in an open topped tank and completely submerged in the creosote or oil based preservative liquid, which is then heated to approximately 90-100°C. The actual time taken and temperature in this operation, relative to timber size and species and preservative liquid used, to be those which experience has shown to be adequate.

After the timber and the liquid have been heated, they are allowed to cool, or the hot liquid may be drained off and replaced by cooler liquid and the whole tank and contents allowed to cool to a suitable temperature. During treatment timber must be completely submerged and sufficient allowance must be made for uptake and additional preservative used so that no part of any timber will become exposed during treatment. Timber becoming exposed above the surface of the liquid at any stage of the process should be reimpregnated.

Process Specification P6

MOMENTARY IMMERSION (DIFFUSION) PROCESS

i.e., Open Tank
Spray tunnel
Chain dip
Hand dip

1. Preservatives

The following preservatives are approved for use with this process and are defined in Section F: Formulations:

Boron Compounds. (To be used in proportions to give solutions with the equivalent formulation of $Na_2B_8O_{13}$).

2. Commodities

This process may be used to treat produce as defined in commodity specification C8.

3. Moisture Content of Produce Before Treatment

Immediately before treatment, timber shall be in the green-off-saw condition.

4. Treatment (see also clause 7)

The material shall be treated in a plant as described in the introduction to this section (PP).

4.1 *Timbers up to 50mm in Thickness*—Timber shall be dipped or sprayed so that each surface of each individual piece is throughly wet with treating solution. Timber block-stacked for immersion is to be loosely tied or wired to permit the solution to thoroughly wet all surfaces.

4.2 *Timbers Over 50mm and up to 75mm in Thickness*

4.21 Open Tank

Either:

4.211 The timber to be immersed in fillet for 30 minutes; or

4.212 Timber block-stacked for immersion shall be immersed twice, the second immersion to take place between 2 and 4 days after the initial immersion. During the intervening period, the timber is to be covered with polythene or other approved drapes to prevent loss of moisture.

4.22 *Spray Tunnel, Chain Dip, and Hand Dip*—The timber is to be sprayed or immersed twice, the second immersion to take place between 2 and 4 days after the initial immersion. During the intervening period the timber is to be covered with polyethylene or other approved drapes to prevent loss of moisture.

* New Zealand Timber Preservation Association

4.3 *Rain-Wet Timber*—Rain-wet timber shall not be treated, and precautions shall be taken to ensure that after immersion timber does not become rain-wet while being conveyed to diffusion storage.

4.4 *Solution Concentration*

4.41 *Control*—The concentration of the treating solution shall be determined by analysis or from its specific gravity by reference to a chart (approved by the Authority) showing the relationship of concentration to specific gravity and temperature. The specific gravity of the sample of the solution shall be determined with a standardised hydrometer corrected for temperature. At least once in each calendar month of operating, an analysis of the solution shall be made by an analyst, or in a laboratory approved by the Authority.

4.42 The solution concentration, temperature, and diffusion time shall be as set out in the table at clause 7 below.

5. Measurement of Timber Quantity

Timber quantity shall be calculated from its nominal sawn dimensions.

6. Not applicable.

7. Minimum Operating Requirements

The standard minimum schedule of requirements set out below may, in special circumstances, be modified at the discretion of the Authority.

Species	Thickness	Open Tank		Spray Tunnel Chain Dip Hand Dip	
		Solution Concentration of H_3BO_3	Temperature	Solution Concentration of H_3BO_3	Temperature
	mm	percent	°C	percent	°C
Group A— Kahikatea Kauri	25	12	20	15	20
Pines— Muricata Maritime Ponderosa* Radiata Strobus Redwood	40 50 75	15 15 18†	20 20 25†	18 18 18†	25 25 25†

Species	Thickness	Open Tank		Spray Tunnel Chain Dip Hand Dip	
		Solution Concentration of H_3BO_3	Temperature	Solution Concentration of H_3BO_3	Temperature
	mm	percent	°C	percent	°C
Group B—					
Douglas fir	25	15	20	18	25
Pines—					
Slash	40	18	25	21	30
Corsican					
Loblolly	50	18	25	21	30
Totara					
Group Ba—	75	18†	25†	18†	25†
Larch					
Group C—	25	15	20	18	25
Matai	40	18	25	21	30
Miro					
Rimu	50	21	30	24	35
Tanekaha	75	18†	25†	18†	30†
Group D—					
Eucalyptus fastigata	25	30	35	35	50
Kohekohe					
Mangaeo					
Pukatea	40	35	50	40	55
Beech—					
Hard					
Red					
Silver	50	40	55	45	60
Hinau					
Rewarewa					
Taraire	60	30†	45†	30†	50†
Tawa					

*Diffusion time for 50mm as for Group Ba.

†Double dipping is required except for timber immersed for 30 minutes in the open tank in fillet.

8. Minimum Diffusion Periods

——	25mm	40mm	50mm	60mm	75mm
Groups A, B, C	4 weeks	6 weeks	8 weeks	-	16 weeks*
Group Ba	5 weeks	8 weeks	10 weeks	-	16 weeks*
Group D	6 weeks	9 weeks	12 weeks	16 weeks	-

*12 weeks for approved pine species.

9. Diffusion Storage

9.1 After immersion in the solution, timber shall be held under approved restricted drying conditions for a minimum period as shown in clause 8 above and until the concentration of boric acid equivalent of 0.1 percent for softwoods and 0.2 percent for hardwoods has been attained in the sapwood core as required by the commodity specification.

9.2 No timber shall be removed from diffusion storage prior to the completion of the full diffusion period under the control of the plant operator at the treating plant.

10. Not applicable.

Process Specification P7

STEAM AND COLD QUENCH (DIFFUSION) PROCESS

1. Preservatives

The following preservatives are approved for use with this process and are defined in Section F: Formulations:

Bolit
Boron compounds

2. Commodities

This process may be used to treat produce as defined in commodity specifications C5 (limited to battens in not more than 50mm x 40mm in section) and C8.

3. Moisture Content of Produce Before Treatment

3.1 *All approved Species EXCEPT Radiata pine*—Immediately before treatment, the timber shall be in the green-off-saw condition (i.e., in the high state of moisture normally found in freshly sawn timber).

3.2 *Radiata pine*—Radiata pine may be either in the green-off-saw condition or pre-dried to a moisture content not exceeding 25 percent.

4. Treatment

The material shall be treated in a plant as described in the introduction to this section (PP).

4.1 *Steaming*

4.11 *Building Timbers*—Timber shall be stacked with fillets between each layer of boards, transferred to the treatment chamber, steam heated to 82°C and maintained at this temperature for not less than 3 hours.

4.12 *Battens*—Battens shall be placed in the treatment chamber with horizontal fillets separating not more than 100mm of timber and vertical fillets separating not more than 250mm of timber, steam heated to 100°C and maintained at this temperature for not less than 6 hours.

4.2 *Draining Condensate*—At the completion of the steaming period, condensed water shall be drained from the treating chamber and the charge flooded with the treating solution immediately.

4.3 *Solution Concentration*

4.31 *Requirement*—For minimum solution concentrations see clause 7, Minimum Operating Requirements below.

4.32 *Control*—The concentration of the treating solution shall be determined by analysis between each charge and any necessary adjustment made. The solution shall be thoroughly mixed before sampling. At least once in each calendar month of operating an analysis of the solution shall be made by an analyst, or in a laboratory, approved by the Authority.

4.4 *Cold Quenching*—The cold treating solution shall be admitted to the chamber to a sufficient level to ensure that all pieces are wholly submerged for the duration of the quenching period. The minimum quenching period is defined in clause 7, Minimum Operating Requirements below.

5. Measurement of Timber Quantity

Timber quantity shall be calculated from its nominal sawn dimensions.

6. Not applicable.

7. Minimum Operating Requirements

The standard minimum schedule of requirements set out below may, in special circumstances, be modified at the discretion of the Authority.

7.1 *Boron Compounds* (Commodity Specification C8 only)

Species	Green-off-saw				Pre-dried to M.C. not exceeding 25 percent		
	Thickness	Solution Concentration of H_3BO_3	Immersion Time	Diffusion Time	Solution Concentration of H_3BO_3	Immersion Time	Diffusion Time
	mm	percent	hours	weeks	percent	hours	weeks
Radiata pine	25	1.5	15	2	1.5	15	—
	50	1.5	64	4	1.5	15	—
	75	N/A	N/A	N/A	1.5	60	—
Kahikatea Matai Rimu Miro	25	1.5	15	2	N/A	N/A	N/A
Tawa Hinau Mangeao Taraire Rewarewa	25	2.0	15	2	N/A	N/A	N/A
Kahikatea Matai Rimu	50	1.5	64	4	N/A	N/A	N/A
Tawa	50	2.5	64	6	N/A	N/A	N/A

7.2 *Bolit*

7.21 **Building Timbers** (commodity specification C8)
Species—Radiata pine up to 50mm thick and pre-dried to moisture content not exceeding 25 percent.
Minimum Solution Concentration—1.25 percent.
Immersion Time—Fifteen hours with a minimum temperature drop of 30°C.
Diffusion Time—Not applicable.

7.22 **Battens** (commodity specification C5)
Species—Radiata pine, Eucalyptus fastigata in 50mm x 40mm in section and in a green-off-saw condition.
Minimum Solution Concentration—Radiata 5 percent. Eucalyptus fastigata 6 percent.
Immersion Time—Six hours with a minimum temperature drop of 30°C.
Diffusion Time—Two weeks.

8. Diffusion Times

Diffusion times are set out in clause 7 above.

9. Diffusion Storage

9.1 After immersion in solutions of boron compounds or Bolit, timber shall be held under approved, restricted drying conditions for a minimum period as shown in clause 7 above and until the concentration of preservatives has been attained in the timber as required by the commodity specification.

9.2 No timber shall be removed from diffusion storage prior to the completion of the full diffusion period under the control of the plant operator at the treating plant.

10. Not applicable.

Process Specification P8

ACCELERATED BORON DIFFUSION PROCESS

1. Preservatives

The following preservatives are approved for use with this process and are defined in Section F: Formulations:

Boron Compounds

2. Commodities

This process may be used to treat produce as defined in commodity specification C8.

3. Moisture content of Produce before Treatment

Immediately before treatment, the timber shall be in the green-off-saw condition.

4. Treatment

The timber to be treated shall be placed in a suitable vessel and covered completely with treating solution. The temperature of the solution shall be raised to 90°-95°C and held for the length of time stipulated in clause 7. The time may be calculated from when 90°C is reached but at least two-thirds of the total time must be not less than 93°C. The solution shall then be allowed to cool, or be replaced with cold solution, and held for the time stipulated in clause 7 or longer if necessary until the solution temperature is below 50°C. The timber shall then be held in diffusion storage at elevated temperatures as detailed in clauses 8 and 9.

5. Measurement of Timber Quantity

Timber quantity shall be calculated from its nominal sawn dimensions.

6. Not applicable.

7. Minimum Operating Requirements

7.1 *Species and Sizes*—The process may be used for timbers up to 50 mm thick of the following species: radiata pine, tawa, rimu, totara, kahikatea, kauri.

7.2 *Spacers*—Spacers of at least 10 mm thickness shall be used between every fourth tier for timber up to 25 mm thick and every second tier for timber of greater thickness.

7.3 *Duration of Hot Bath*—The hot bath, as defined in clause 4,

shall be maintained for 3½ minutes per millimetre of board thickness (times to be taken to the nearest 10 minutes).

7.4 *Duration of Cold Bath*—The cold bath duration shall be the same as for the hot bath, or longer if necessary for the final temperature to be less than 50°C.

7.5 *Solution Concentration*—The minimum solution concentration shall be 8.5 calculated as boric acid (H_3BO_3) equivalent. Solution concentration should be checked by titration after every topping-up operation.

7.6 *Specified departures from Standard Schedules.* Any departures from the standard schedules for individual plants, species, or sizes shall be at the discretion of the Timber Preservation Authority.

8. Minimum Diffusion Period

Diffusion may be carried out at temperatures of 50°C or 70°C.

The minimum diffusion period for timber held at 50°C shall be 3½ days for every 25 mm thickness and for timber held at 70°C shall be 2 days for every 25 mm thickness. (Times to be taken to the nearest half day.)

Any departures from the standard minimum diffusion periods shall be at the discretion of the Timber Preservation Authority.

9. Diffusion Storage

Diffusion storage shall be carried out in an enclosed building or vessel in which the relative humidity will be maintained at not less than 95 percent. The temperature shall be controlled by a thermostat to within ± 2°C of the specified diffusion temperature.

10. Not applicable.

APPENDIX 2

Process Specifications for Treatment of Timber by Vacuum/Pressure Impregnation

Introductory Note:

Because of very fundamental difference between the structure of hard-woods (Angiosperms) and soft-woods (Gymnosperms) especially in the size and distribution of fibres or fibre tracheids, rays and axial parenchyma and large void space associated with vessels in hardwoods, the treatment schedules used for conifers may give quite unsatisfactory results for hardwoods. Thus in conifers, fibre tracheids, the strength giving elements, make up some 90% of the total wood volume, with parenchyma and resin canals making up the remainder. In temperate conifers the major differences are between early wood and late wood and of course sap and true wood.

In a permeable softwood, the gross retention obtained usually gives a fair estimate of the retention in the fibre - tracheids. However, in a hardwood, the gross retention is dominated by the retention in the vessels and parenchyma and is likely to be unrelated to the retention in the fibres, the main strength giving elements. In many hardwoods significant penetration of fibre lumen may not even start until all the vessels and parenchyma lumen (void space) have been filled with preservative and this may require about 80% total preservative solution. In the worst cases we thus use up to 80% of the total preservative before we start to treat the fibres towards the end of the treatment cycle. It may be true that the final 1% or so of the total preservative uptake is what finally gives what protection against soft-rot fungi that is obtained and so the final stages of treatment take on special importance.

The standard procedure in specifying the final stage of treatment is to set a final rate of flow which, in this standard, is the uptake of preservative in litres per cubic meter of charge volume in a ten minute period. That treatment of each charge reaches the final rate of flow is a critical factor in meeting this standard and all treatment plants should be kept in a good state of repair, free from leaking valves and door seals so that this final rate of flow may be determined accurately.

Becuase the rate of uptake and final retention obtained varies greatly between timber species, only those timbers listed in similar retention groups shall be treated together in the same charge and then all pieces should be of similar cross sectional area and length.

Process Specifications

Bethell (Full Cell) Vacuum Pressure Process

1. Application. The treatment of all timber, either round or sawn for utilization classes U2, U3, U4, U5 and U6 shall be by the Bethell (Full Cell) Vacuum Pressure Process as described in this Appendix.

2. Retention Groups. In Schedule 2 of this standard 12 retention groups are listed. Timber species within each retention group may be treated in the same charge provided that all pieces in the charge are intended for the same end use and have the same form.

Thus charges shall not consist of both natural rounds and sawn timber, or of fence posts and utility poles and etc.

3. Preservative Solution Strength. In Schedule 2 of this Standard, recommended preservative solution strengths of a high copper and a low copper preservative are listed for each timber species according to its utilization class.

4. Treatment of Mixed Charges. When a charge consists of more than one timber species within a utilization class/retention group, the solution strength used shall be the highest for timber species in that charge.

5. Hydraulic Pressure. Where a mixed charge is being trated and this Standard requires that one of the timber species in that charge will be treated at 2100 kPa, the whole charge will be treated at 2100 kPa.

6. Non Availability of plant capable of reaching 2100 kPa hydraulic pressure

When the v/pressure cylinder is for use at 1400 kPa or lower and it is desired to treat a timber species for which a hydraulic pressure of 2100 kPa is specified in this standard, the final rate of flow specified in this standard for the timber species/utilization class must be reached and the maximum hydraulic pressure available maintained for an additional hour.

7. Treatment Schedule.

7.1 Initial Vacuum. An initial vacuum of at least 50 mm of mercury absolute shall be drawn and maintained for at least 45 minutes and any further period required so that during the pressure stage, the time taken to reach a hydraulic pressure of 1300 kPa shall not exceed 15 minutes.

7.2 Pressure. The working pressure shall be as set out in Table 2.1 below, and shall at no time be more than 100 kPa less than that specified.

Utilization Class	Working Pressure				
	Note 1		Note 2		Note 3
U2	340 kPa	or	1400 kPa	or	2100 kPa
U2	340 kPa	or	"	or	"
U3	340 kPa	or	"	or	"
U4	340 kPa	or	"	or	"

Note 1. Where prior to the publication of this standard, treatment plants for use at hydraulic pressure of at least 340 kPa (50 Psi) were in operation, these plansts may be used for treatment of timber for utilization classes U2, U3 and U4 provided that this standard does not call for working pressure of 2100 kPa for the timber species being treated.

Note 2. Further to paragraph 6 of this Appendix where a working pressure of 2100 kPa is specified and a treatment plant in operation at the time of publication of this Standard, is rated at 1400 kPa, these timber species may be treated provided that after reading the specified final rate of flow the pressure is maintained for one further hour.

However, in any treatment plant installed subsequent to the publication of this Standard, the specified working pressure must be used.

Note 3. A working pressure of 2100 kPa rather than 1400 kPa has been specified for those timber species in which significant additional uptake of and/or improved distribution of preservative can be obtained.

FINAL RATE OF FLOW IN LITRES PER 10 MINUTES PER CUBIC METER

RETENTION GROUP

Utilisation Class		1	2	3	4	5	6	7	8	9	10	11	12
U1		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
U2		14	14	14	13	12	12	10	8	8	8	6	3
U3		14	14	14	13	12	12	10	8	8	8	6	3
U4	Round	7	7	7	6	6	6	5	4	3	3	3	1.5
U4	Sawn	14	14	15	6	6	6	5	4	3	3	3	1.5
U5	Round	3.5	3.5	3.5	3	3	3	2	2	1.5	1.5	1.0	0.5
U5	Sawn	7	7	7	3	3	3	2	2	1.5	1.0	1.0	0.5
U6	Round	7	7	7	3	3	3	2	2	1.5	1.0	1.0	0.5
U6	Sawn	7	7	7	3	3	3	2	2	1.5	1.0	1.0	0.5

Note I Final rates of flow herein are based on total charge volumes

Note 2 These final rates of flow are subject to change when so indicated by the PNG WPA.

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LIGHT TIMBER FRAMING CODES FOR DEVELOPING COUNTRIES*

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ABSTRACT

The features of timber frame construction, which merit its consideration as a building system for developing countries, are outlined. The purpose of a code for timber frame buildings is discussed and its main features listed. A procedure is suggested for formulating a timber frame code for developing countries.

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Appendix - Excerpts from construction guidelines for single room dwelling

1. INTRODUCTION

(a) Definition of light timber frame construction

Light timber frame construction is the term commonly used to describe a building system using a frame constructed of relatively light, and relatively closely spaced, sawn timber members to support the cladding and lining materials. It is used mostly for housing and small industrial buildings but may also be used for in-fill panels and partitions in larger buildings.

(b) Structural characteristics

The relatively close spacings and plentiful fastenings ensure that a high degree of structural redundancy and load sharing exists within the structure. Weaker and less stiff members shed load (via crossing members and claddings) to the stronger and stiffer members so that the strength of the structure as a whole is related more to the average strength of the members than the minimum strength. Cladding and lining materials also contribute to the structural performance of the frame.

The close spacings mean lightly loaded bending members with high span/depth ratios, so that stiffness rather than strength generally determines the size of the members used in normal wind loading conditions. However, in the case of hurricane-resistant, light timber frames with full internal pressure, the size is governed by strength considerations. Thicker, more heavily loaded members are used to support wall and floor frames and span openings, and strength may govern in these cases. In some situations it may be necessary to use a larger member than is required by either strength or stiffness considerations simply in order to accommodate the fasteners.

(c) Advantages

Light timber frame construction is the traditional building method in a number of more industrialised countries, including Scandinavia, North America, Australia, and New Zealand, and has maintained its popularity for housing in the face of competition from other materials

and building systems. It can be adapted economically to varying building styles and production methods. Both low and high cost timber framed housing performs well over a wide range of climatic conditions.

Production methods range from the one-man building firm, operating with hand tools and a truck, through to the capital-intensive, high-production, automated-frame manufacturing plant. These operations can coexist within the same economic environment.

Methods of assembly may be quite tolerant of dimensional innacuracy and timber shrinkage, so it is possible to build with green timber. This is easier to nail than dry timber and dries out in place under the restraint of surrounding structural members and finishing materials. Sawn timber may be used but planed timber is usual as the more accurate dimensions speed construction.

The load-sharing nature of the structure allows low grades of timber to be used safely and economically.

Preservative treatment of non-durable timber species, together with good detail design to control condensation and moisture entry, give the frame an indefinite service life against insect and fungal attack. Correct detail design also contributes to structural strength. Well constructed timber frame housing, in which members and frames are properly tied together, has a good record of resistance to high winds and earthquakes.

Light weight construction facilitates transport and lifting of the finished structure and reduces risk to life if failure does occur.

Properly managed forests constitute a renewable timber resource, from which sawlogs can be extracted with minimal impact on the environment. Compared with other building materials, timber requires relatively low inputs of energy for extraction and processing. No water is required on site for assembly of timber structures.

Timber frames do not rust and can be insulated to a high standard. The flexibility of timber frame construction allows repairs, alterations, extensions, and even relocation of the structure to be carried out with minimal difficulty and expense.

These advantages of timber frame construction commend it as a building system in any country where suitable materials are available.

2. PURPOSE AND SCOPE OF CODE

(a) Purpose

The purposes of codes in developed countries are first, and most importantly, to assist local authorities in ensuring safe and healthy building construction, and second to educate all involved in the design and building process. Timber frame building methods are taught through a combination of apprenticeships and courses in technical colleges. Text books and manuals, based on code requirements, are widely available.

In developing countries, where the method is not well known, the educational role probably comes first. As a result the code could appropriately resemble a manual in content and format.

(b) Scope

Rather than simply dealing with timber-related aspects of timber frame construction, it is better, and will increase the likelihood of obtaining a satisfactory building, if all constructional aspects of a timber frame building are dealt with in a single comprehensive code. For example, if concrete floors are a desired option, the construction details of these floors should be included in the code.

Including all possible structural options in a code would result in too big a document, consequently a selection of options will need to be made. This should be done on the basis of a careful study of local building forms, and cultural and climatic requirements. The availability of materials, fasteners, building equipment and tools, and the level of building expertise should all be ascertained before setting out the main framework of a code.

The implications of such an approach are that it is unlikely that a single code could be written that would be acceptable to all developing countries. Rather than writing a model code and introducing it and the timber frame construction system to a developing country, it is suggested that the exercise start with a study of that country's requirements and resources, so that a code can then be written around them.

What is required with this approach is not a model code itself but a set of guidelines for the production of a code. The following observations are based on the author's personal experience with the

New Zealand Code of Practice for Light Timber Frame Buildings (NZS 3604:1984, first published in 1978)[1] and on discussions with the authors of the equivalent Fiji code published in 1985[2]. It is hoped that these will prove useful guidelines for the production of codes in other countries. Excerpts from the above-mentioned codes are included to illustrate points made.

3. BASIC REQUIREMENTS OF A CODE

(a) Format

Codes suffer wear and tear from frequent reference so they need good quality paper and stout covers. For ease of use and ammendment, an A4 format in a 4 hole ring binder is recommended. Unfortunately this type of binding is not very durable as the punched holes wear and need reinforcing. Paper with a reinforced edge would be ideal if this can be obtained.

The A4 format is well suited to text with illustrations which should be placed close to the text to which they relate.

A contents list and an index which refer to clause numbers rather than page numbers is helpful.

(b) Contents - General

The choice of content of the code will be greatly influenced by the answers to two questions:

"What is the purpose of the code?"

"For whom is it written?"

Answers to the first question might be:

"To control the standard of building construction for the health and safety of occupants."

or "To inform builders about good building practice."

or "To instruct newcomers to the timber frame building system."

To the second question, answers might be:

"Building designers, draughtsmen, building inspectors."

or "Qualified builders, building designers, inspectors, and draughtsmen."

or "People with no previous construction experience wishing to build a timber frame house."

In developing countries it is likely that the last answers to the two questions are the most appropriate. If the code is written more as a manual catering to the lowest level of knowledge and experience it doesn't necessarily compromise its role as a regulatory document. In the New Zealand code, a conscious decision was made to move away from the austere legal document of the previous code to an illustrated manual type code with improved readability. This was done by adopting a "means of compliance" format in which the brief legal requirements were published separately in the form of broad performance statements. The code of practice then became a technical document written to inform people how to build timber frame structures complying with the legal requirements.

For timber frame to be successfully introduced to a country and become an accepted building method, structures must from the start be well built and free from major structural defects. If this is to happen, good communication is needed between the code writers and the reader, i.e., the message must get across.

Ideally the code should include plenty of good quality illustrations accompanied by a simply written text. As far as possible, non-legal and not too technical language should be used. Clarity and simplicity help to ensure that the regulatory process is not a source of abuse by officials.

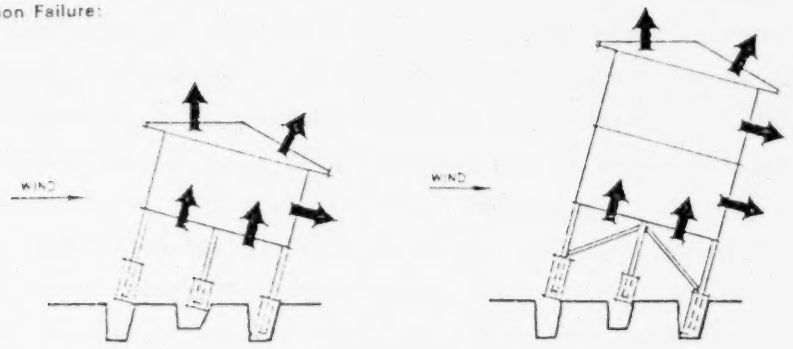
The broad areas to be covered in the content are:

1. The general form of the building.
2. Details of construction - particularly connections.
3. Span tables.

Illustrations should be used liberally to convey information in the first two sections. An understanding of how the structure works, and how the loads it is expected to withstand are resisted by members and connections, can be conveyed by diagrams of failure modes under loading (see Fig. 1). Including these, together with detailed diagrams of all vital structural connections, will improve the chances of obtaining a building free from major structural defects. Even in developed countries with a tradition of timber frame building, structural defects are not uncommon and usually arise as a result of lack of appreciation of what is needed, rather than through negligence.

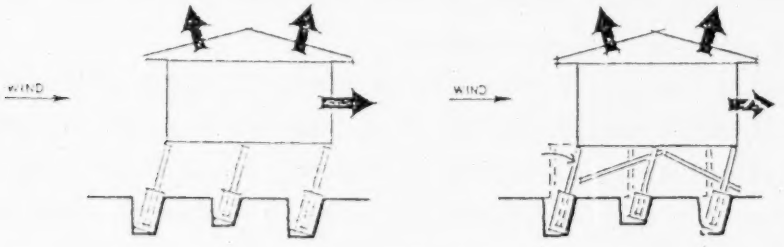
Figure 1 - Example of failure mode diagram from Fiji Pine Code

Foundation Failure:



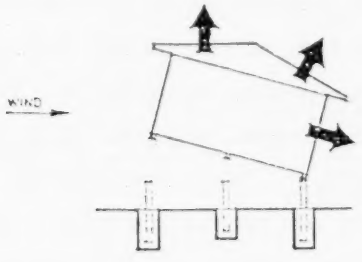
FAILURE: 1. Pile foundations have inadequate depth and mass to resist uplift.
2. Pile foundations constructed in soft ground with inadequate shear friction resistance to prevent the pile from being pulled out of the ground.

REMEDY: Provide deep and heavy footings.



FAILURE: 1. Pile foundations at inadequate depth and width to resist overturning.
2. Pile foundations constructed in soft ground unable to resist overturning.
3. Pile height exceed code maximum for cantilevered piles and are overloaded.
4. Piles exceeding 1.2 m. which are not laterally supported with diagonal braces.

REMEDY: Provide deep and wide foundations with bracing as required by this code.



FAILURE: 1. Connections between bearers and piles fail.
2. Connections of braces to piles or sub-floor framing fail.

REMEDY: Provide adequate connections between bearers and piles and braces and piles.

Causes and Effects of Foundation Failures

Where light timber construction is introduced to a country with a tradition of building in heavy materials, it is vital that an appreciation of the wind uplift loads on the timber frame, and the need for clearly defined and well constructed load paths from roof to ground to resist these uplift forces, is conveyed. Similarly with lateral forces due to wind and earthquake. For lateral loads the paths are less easily defined so the diagrams will present a challenge to the illustrator.

Depending on the level of sophistication of the community into which the system is being introduced, it may be desirable to include illustrations and sample plans of complete houses built to the code. Cutaway views showing framing and connection details with references to the relevant pages of the code could be used to summarise the building system in a few pages (see Appendix).

(c) Contents - Specific

It is logical to structure the code so that specific subjects are discussed in the same order as they arise during the planning and building process itself. For example (a) the building system and its limitations, (b) materials and components, (c) requirements of a building site, (d) major structural components (from foundations to roof), and (e) finishing. Fastening systems are best dealt with along with the components to which they relate. Appendices may be used to describe different options and provide additional information.

With some minor variations, the New Zealand and Fiji framing codes follow the sequence of topics listed below:

1. Introduction
   (a) Description of timber frame system and design options provided in the code.
   (b) Limitations on loading, dimensions, number of stories.
   (c) Definition of terms used. Diagram of structure with main components labelled.
   (d) Use and interpretation of code.
2. Materials and components
   (a) Timber and wood-based products. Species, grade, sizes, finish, treatment, moisture content, type, specifications.

(b) Fasteners. Sizes and specifications for nails, screws, bolts, proprietary fasteners.

3. Site requirements

Profile and stability, flooding, soil bearing strength, site preparation.

4. Foundations and subfloor framing
   (a) Structural action diagrams showing failure modes vertically and horizontally.
   (b) Systems to resist vertical loads.
   (c) Pile types and footings.
   (d) Systems to resist horizontal loads.
   (e) Bracing.
   (f) Bearers.
5. Floors
   (a) Structural action and failure diagrams.
   (b) Joists.
   (c) Flooring.
6. Walls
   (a) Structural action and failure diagrams
   (b) Systems to resist vertical loads
   (c) Wall framing. Studs, plates, lintels, intersections
   (d) Systems to resist horizontal loads
   (e) Wall bracing
7. Posts.
8. Exterior wall cladding.
9. Interior wall lining.
10. Roofs
   (a) Structural action and failure diagrams
   (b) Systems to resist vertical loads
   (c) Roof trusses
   (d) Framed roofs
   (e) Systems to resist horizontal loads
   (f) Roof bracing
   (g) Ceiling framing
   (h) Platforms (for water tanks) in the roof space
11. Roof coverings.

12. Ceiling lining.
13. Appendices
    (a) Sample plans covering a range of sizes and styles
    (b) Illustrations of completed houses

4. CALCULATION OF SPAN TABLES AND FASTENING REQUIREMENTS

With few exceptions, most users of the code would be likely to find numerical performance information of less interest than descriptions of the form of construction. Nevertheless, the successful introduction of the timber frame system depends on a correct specification of performance requirements. These figures need to be accessible to specialist groups, but not necessarily incorporated into the code, as this would make it bulky and less readable. The code itself should be a concise and practical document which enables builders to meet performance requirements economically.

For developing countries a specification type of code is more appropriate than a performance code, but it is important that the basis for the calculations be set out in an associated document so that future revisions or extensions of the code may be made knowing the basis for the original recommendations.

(a) Loading and deflection limitations

Where a loading code is available this may be used to establish wind, earthquake, snow, and occupancy loads. Otherwise loading codes from other countries may be used in association with local climatic and seismic data.

Deflection limitations are generally poorly dealt with in loading codes but as discussed in section 1(b) often dominate the construction of span tables for light timber framing. If local guidance is inadequate then other national codes and publications[3,4] may be helpful. Although the calculated stiffness of say two joisted floors under a given uniform loading may be the same, their performance may differ considerably under the more concentrated loads of normal use because of different amounts of load sharing. The different load sharing properties of different struc-

tures should be considered when formulating deflection limitations, as should any perceived local preferences for stiffer or more lively floors.

(b) Material properties

Knowledge of the timber available for construction may vary from crude density estimates through small clear specimen test data to detailed in-grade test data. A system of grading timber allows more efficient use of the resource and a more consistent standard of construction. Where in-grade data are not available then the classification system developed for the Standards Association of Australia[5] may be used to derive basic strength data for span table calculations. A similar grouping system has been developed for the derivation of fastening properties.

(c) Span tables

Span tables present the results of engineering calculations for defined structural components, material properties, and performance requirements. They are compromises between engineering efficiency, which demands large tables with small steps of the variables, and code usability, for which simpler, shorter, more easily read tables are required. For developing countries the compromise should be made more in favour of code usability. If possible, tables should be presented as finished answers in terms of member size or span without further calculation being required. Full documentation of the basis for their calculation should be available in supplementary reports. The ease with which a table can be used is dependent on the author, editor, graphic designer, and printer. The following guidelines have been found useful.

1. Table variables should be ordered so that an increase in member size results from going from top to bottom and/or left to right.
2. Rounding to 0.1 of a metre for span tables is generally sufficiently precise.
3. Where few variables are involved, such as in joist or rafter tables, the tables can give allowable member spans as the answer for given sizes and spacings. Where many variables are involved, such as in stud, plate and lintel tables, an allowable member size is the most appropriate tabulated answer.

4. Tables should relate to one another where appropriate. For example, tables of pile spacings should relate to bearer row spacings which should be covered in the joist span tables.

The calculation of span tables is invariably a computing job so that undue simplification of the number of loading cases or of other assumptions simply to ease the calculation load is unnecessary. Deflection (bending and shear) and strength calculations for dead, live, and dead-plus-live loads should all be included, with allowance for load sharing made where appropriate. Use of the more rational methods developed recently to account for partial composite action and lateral load redistribution[6] is probably not yet warranted.

Where timber is installed green and allowed to dry in place it is generally appropriate to use dry-strength values and shrunk sizes as this is the condition in which the members will be loaded for the greater part of their lives. Taking into account the large size effect which occurs with timber loaded in shear, the design of short span bending members, such as plates, need not be dominated by shear strength considerations. Deflection criteria for these members might in some circumstances be more appropriately expressed as absolute deflection limits rather than as proportions of the span. If there is a possibility of machine graded timber being available, some thought could be given to preparing stiffness based span tables for mixed species as proposed by Kennedy[7].

(d) Fastening recommendations

Fastening systems should be simple, easily inspected, where possible based on locally available materials, skills and tools, and clearly illustrated in the code alongside the components to which they relate. Nails and light-gauge metal strap, through which nails may be driven, meet these criteria and have been specified extensively in the Fiji Pine framing code. Fatigue testing of these strapped connections has demonstrated their resistance to simulated cyclone loading although their load capacity is reduced somewhat where a twist in the strap is necessary to align the strap with members crossing at right angles.

Member sizes may be determined by fastening requirements rather than strength, e.g., timber braces, and where this is so, the member tables should reflect this constraint.

Where extreme uplift loads exist as a result of high wind loadings, it is probably safest to standardise on fastening details. For instance, all vertically loaded joints with nails in end grain are strapped using the same detail, even though calculation may show that some of the straps are unnecessary. Where heavy materials have been used in the traditional building methods, it is important that the code should clearly convey the message that the structural performance of timber frame building systems depends on well constructed, clearly traceable load paths, through members and fastenings, to resist uplift loads and horizontal loads imposed by wind and earthquake. Clear diagrams of forces and failure modes are a good way of doing this.

5. SUGGESTED PROCEDURE FOR FORMULATING A CODE

(a) Prerequisites

1. An economic source of sawn, durable, graded timber to which some strength figures may be assigned.
2. A knowledge of the likely wind and earthquake loadings.
3. Ready availability of fasteners, cladding, roofing, and, if desired, lining material.

(b) Preparation of a design brief for the code

Visits should be made by architects and engineers to determine the size, shape, and cost of houses in relation to the needs, lifestyles, and aspirations of the local people. Questions that should be asked are: should a code be aimed at the top or middle of the market, or both? If the last, should it be printed in a single volume or two separate volumes? What marketing strategy should be employed? The best building system and code in the world may still not find favour with the intended users if it fails to recognise cultural needs and aspirations as well as those of basic shelter.

Sketch plans and structural details should be drawn up and discussed with informed locals. When satisfactory designs and details have been determined, the designs should be tested in actual building; the scope and limitations within which the code will be written can then be

defined. The results of these investigations are written up as the design brief for the code.

(c) Draft for comment

Based on the design brief, a draft code and range of plans can then be prepared for wider discussion within the community.

(d) Publication and presentation

After suggestions have been collated, the draft can be revised in the light of comments received and the final code prepared. Ideally its launch should be made in association with the construction of an exhibition village of real buildings and publication of a variety of plans. The phased introduction of a building system will require careful planning, first to ensure an adequate supply of materials, and second to provide basic training for builders. The regulatory function should be kept to a minimum consistent with achieving desired objectives.

Initial impressions and performance can make or break a new product, so it is particularly important in the early stages that problems are sorted out quickly and the details are followed carefully.

6. LIST OF REFERENCES

1. Standards Association of New Zealand 1984: Code of practice for light timber frame buildings not requiring specific design. NZS3604:1984.
2. Ministry of Forests - Fiji 1985: Fiji pine code of practice for light timber frame building not requiring specific design.
3. Building Research Association of New Zealand 1983: Lintels and beams supporting light timber frame construction. Technical Recommendation No. 2.
4. Reardon, G.F. and Kloot, N.H. 1978: Low rise domestic and similar framed structures. Part 1. Design Criteria (Revised). CSIRO, Division of Building Research Special Report.
5. Standards Association of Australia 1979: Report on strength grouping of timbers. MP45.

6. Forest Products Research Society 1983: Wall and floor systems. Design and performance of light-frame structures. Proceedings 7317.

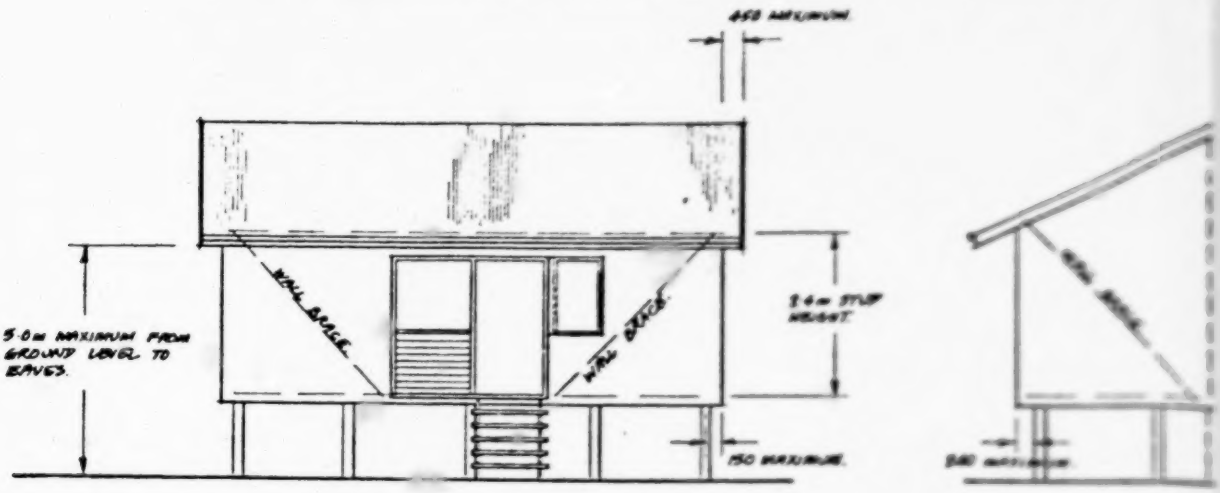
7. Kennedy, D.E. 1969: A new look at mechanical lumber grading. Forest Products Journal 19(6).

ACKNOWLEDGEMENTS

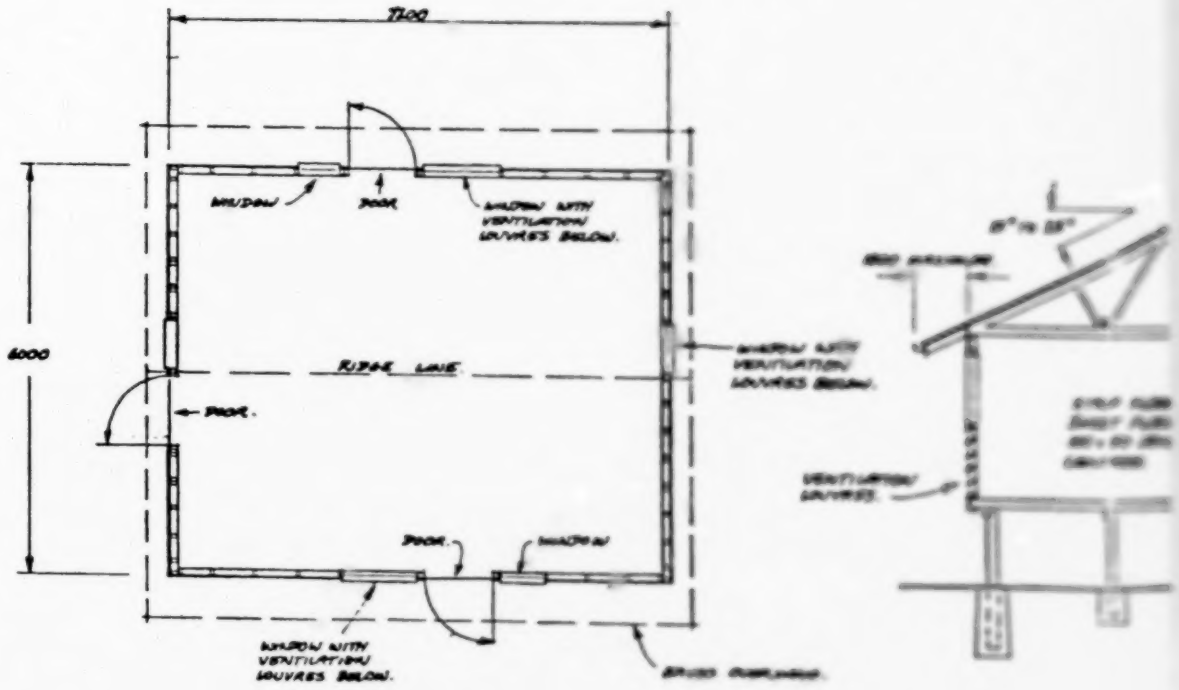
The writer gratefully acknowledges the helpful advice and material received from Mr Ernest B. Lapish, consulting engineer, Auckland, New Zealand and principal author of the Fiji Pine framing code, Mr Graham A.H. Craigie, Architect, New Zealand Ministry of Works and Development who designed a range of houses to the code for Fiji conditions, and Mr Roger L. Williams, District Design Engineer, New Zealand Ministry of Works and Development, Hamilton, New Zealand, who was involved in the initial stages of preparation of this code.

APPENDIX

EXCERPTS FROM CONSTRUCTION GUIDELINES FOR SINGLE ROOM DWELLING



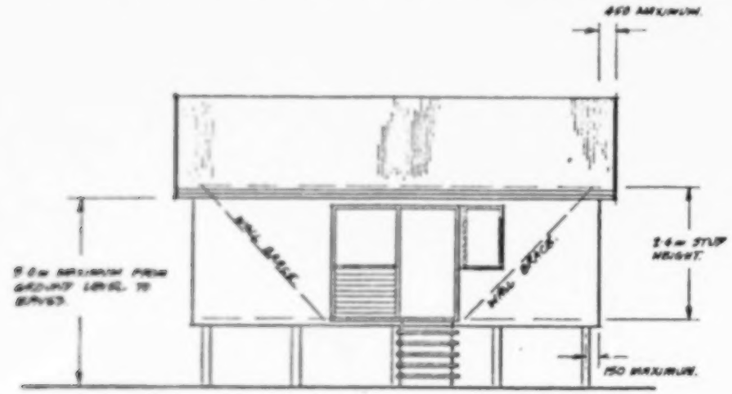
SIDE ELEVATION.



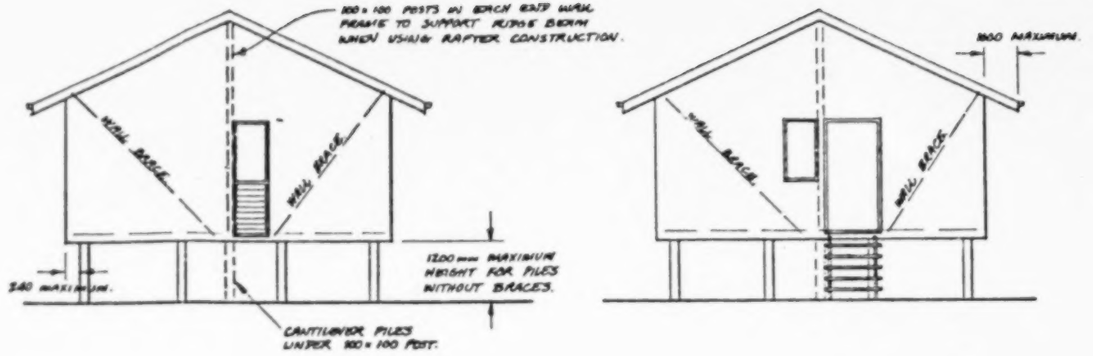
PLAN VIEW.

APPENDIX

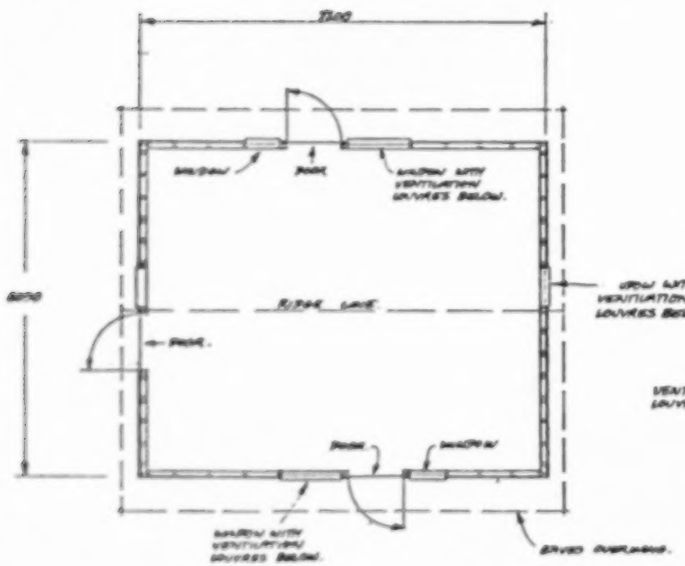
EXCERPTS FROM CONSTRUCTION GUIDELINES FOR SINGLE ROOM DWELLING



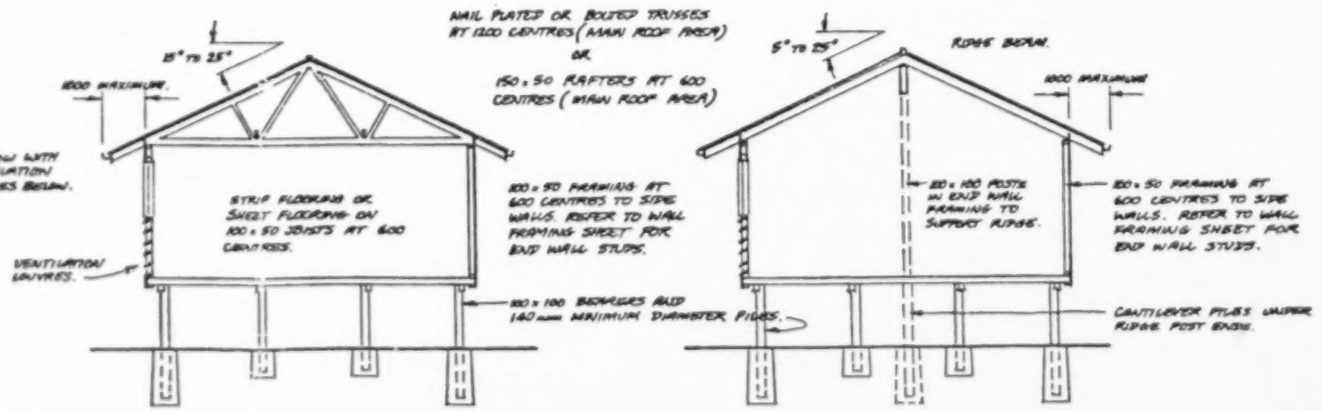
SIDE ELEVATION.


100 x 100 POSTS IN EACH END WALL FRAME TO SUPPORT RIDGE BEAM WHEN USING RAFTER CONSTRUCTION.
WALL BRACE.
WALL BRACE.
1200mm MAXIMUM HEIGHT FOR PILES WITHOUT BRACES.
240 MAXIMUM.
CANTILEVER PILES UNDER 100 x 100 POST.
1800 MAXIMUM.
WALL BRACE.
WALL BRACE.

END ELEVATIONS.



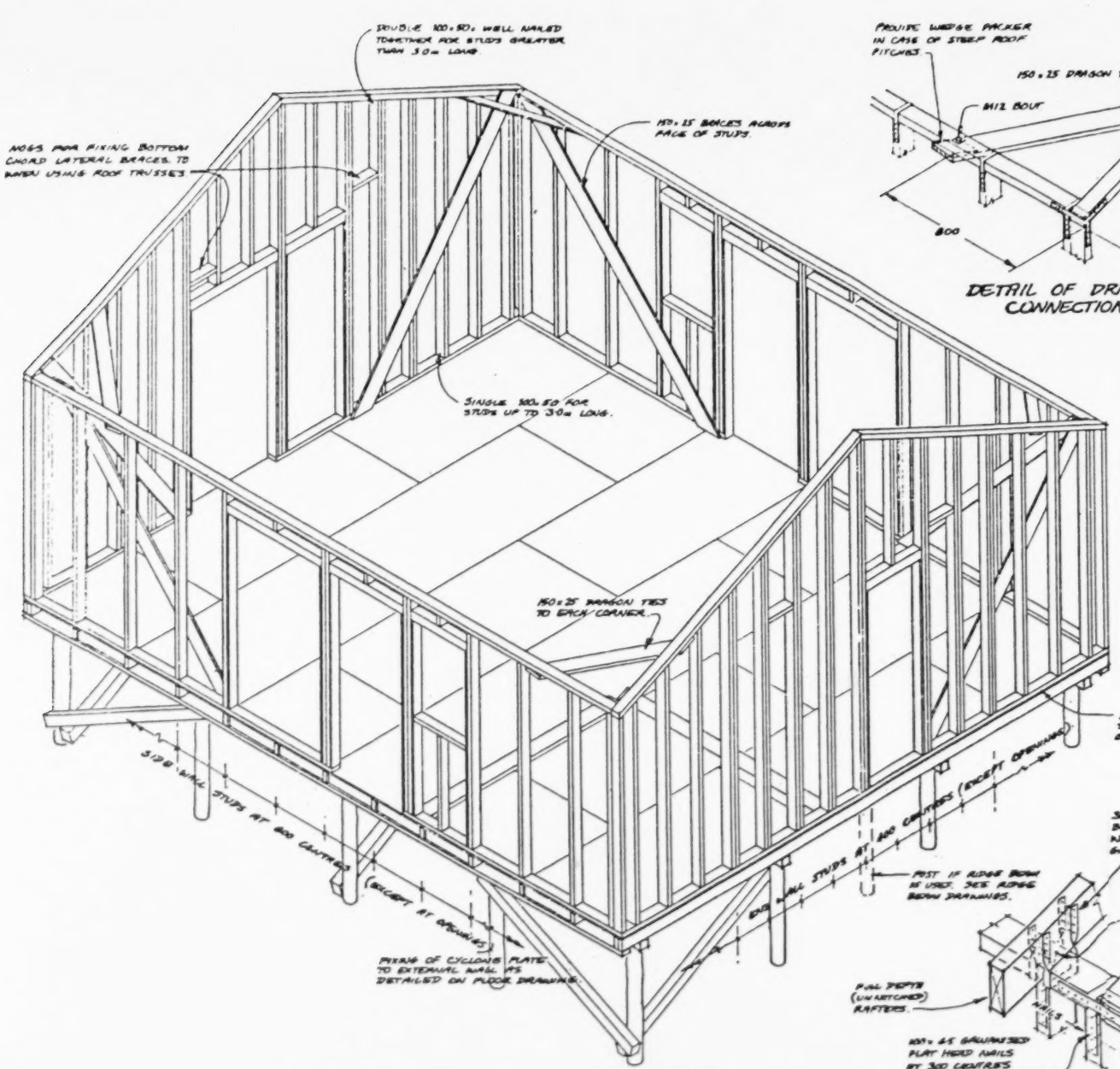
PLAN VIEW.


NAIL PLATED OR BOLTED TRUSSES AT 1200 CENTRES (MAIN ROOF AREA) OR 150 x 50 RAFTERS AT 600 CENTRES (MAIN ROOF AREA)
15° TO 25°
1800 MAXIMUM.
STRIP FLOORING OR SHEET FLOORING ON 100 x 50 JOISTS AT 600 CENTRES.
100 x 50 FRAMING AT 600 CENTRES TO SIDE WALLS. REFER TO WALL FRAMING SHEET FOR END WALL STUDS.
VENTILATION LOUVRES.
100 x 100 BEARERS AND 140mm MINIMUM DIAMETER PILES.
5° TO 25°
RIDGE BEAM.
1800 MAXIMUM
100 x 100 POSTS IN END WALL FRAMING TO SUPPORT RIDGE.
100 x 50 FRAMING AT 600 CENTRES TO SIDE WALLS. REFER TO WALL FRAMING SHEET FOR END WALL STUDS.
CANTILEVER PILES UNDER RIDGE POST ENDS.

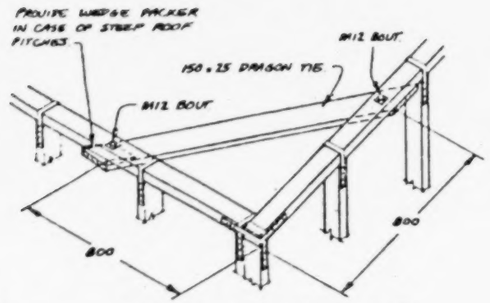
TYPICAL CROSS SECTIONS.

CONSTRUCTION GUIDELINE
FOR SINGLE ROOM DWELLING.

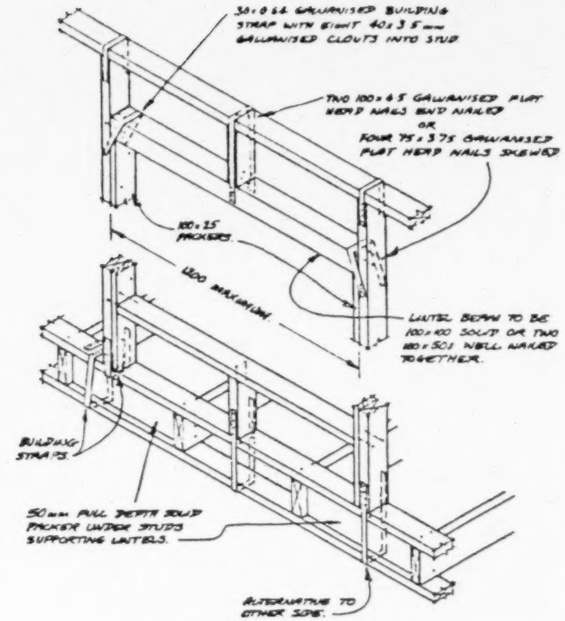
PAGE 1 : THE 72m x 6.0m SMALL BUILDING.


DOUBLE 100 x 50 WELL NAILED TOGETHER FOR STUDS GREATER THAN 3.0m LONG.
NOGS FOR FIXING BOTTOM CHORD LATERAL BRACES TO WHERE USING ROOF TRUSSES
150 x 25 BOARDS ACROSS FACE OF STUDS.
SINGLE 100 x 50 FOR STUDS UP TO 3.0m LONG.
150 x 25 DRAGON TIES TO EACH CORNER.
SIDE WALL STUDS AT 600 CENTRES (EXCEPT AT OPENINGS)
END WALL STUDS AT 600 CENTRES (EXCEPT OPENINGS)
FIXING OF CYCLONE PLATE TO EXTERNAL WALL AS DETAILED ON FLOOR DRAWING.
FIXING OF EXTERNAL WALL TO FLOOR JOISTS AS DETAILED ON FLOOR DRAWING.

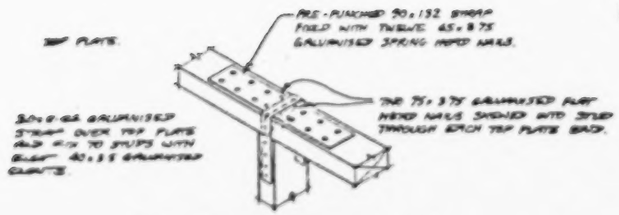
WALL FRAMING.



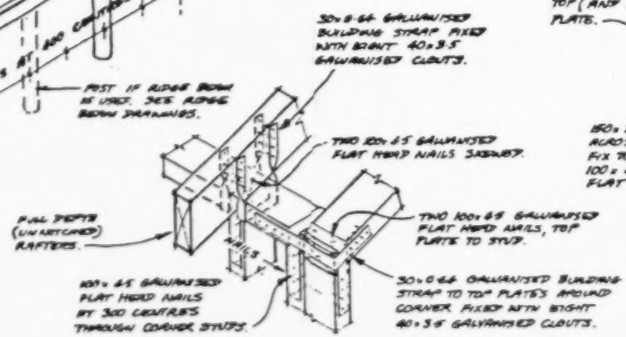
DETRIL OF DRAGON TIE CONNECTION.


30 x 0.6 GALVANISED BUILDING STRAP WITH EIGHT 40 x 3.5 mm GALVANISED CLOUTS INTO STUD
TWO 100 x 4.5 GALVANISED FLAT HEAD NAILS END NAILED OR FOUR 75 x 3.75 GALVANISED FLAT HEAD NAILS SKEWED
100 x 25 PACKERS.
1200 MAXIMUM
LINTEL BEAM TO BE 100 x 100 SOLID OR TWO 100 x 50 WELL NAILED TOGETHER.
BUILDING STRAPS
50 mm FULL DEPTH SOLID PACKER UNDER STUDS SUPPORTING LINTELS.
ALTERNATIVE TO OTHER SIDE.

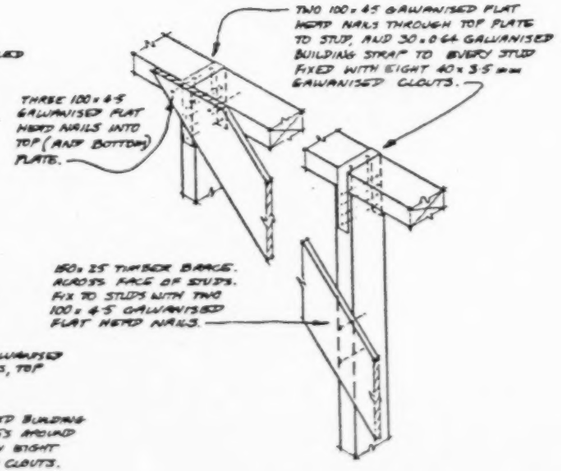
LINTELS.


TOP PLATE
PRE-PUNCHED 90 x 1.32 STRAP FIXED WITH TWELVE 4.5 x 0.75 GALVANISED SPRING HEAD NAILS.
TWO 75 x 3.75 GALVANISED FLAT HEAD NAILS SKEWED INTO STUD THROUGH EACH TOP PLATE END.
30 x 0.6 GALVANISED STRAP OVER TOP PLATE AND FIX TO STUDS WITH EIGHT 40 x 3.5 GALVANISED CLOUTS.

JOINTS IN TOP PLATES.

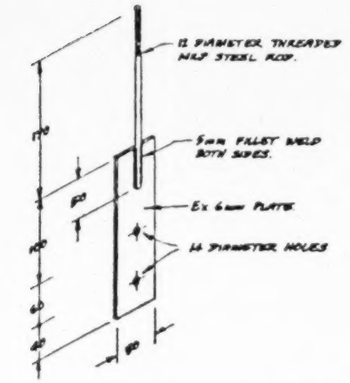

30 x 0.6 GALVANISED BUILDING STRAP FIXED WITH EIGHT 40 x 3.5 GALVANISED CLOUTS.
RIST IF ROOF BEAM IS USED. SEE ROOF BEAM DRAWINGS.
TWO 100 x 4.5 GALVANISED FLAT HEAD NAILS SKEWED.
FULL DEPTH (UNNOTCHED) RAFTERS.
TWO 100 x 4.5 GALVANISED FLAT HEAD NAILS, TOP PLATE TO STUD.
100 x 4.5 GALVANISED FLAT HEAD NAILS AT 300 CENTRES THROUGH CORNER STUDS.
30 x 0.6 GALVANISED BUILDING STRAP TO TOP PLATES AROUND CORNER, FIXED WITH EIGHT 40 x 3.5 GALVANISED CLOUTS.

FIXING OF GABLE END WALLS TO SIDE WALLS AT TOP PLATE LEVEL.

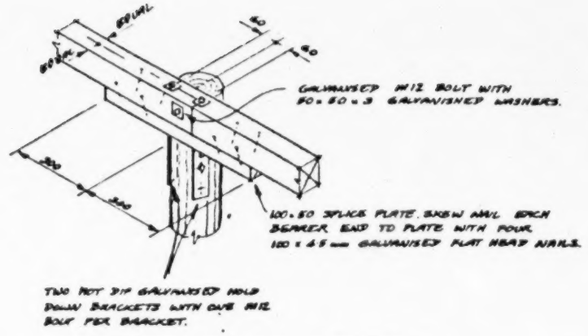

TWO 100 x 4.5 GALVANISED FLAT HEAD NAILS THROUGH TOP PLATE TO STUD, AND 30 x 0.6 GALVANISED BUILDING STRAP TO EVERY STUD FIXED WITH EIGHT 40 x 3.5 mm GALVANISED CLOUTS.
THREE 100 x 4.5 GALVANISED FLAT HEAD NAILS INTO TOP (AND BOTTOM) PLATE.
150 x 25 TIMBER BRACE ACROSS FACE OF STUDS. FIX TO STUDS WITH TWO 100 x 4.5 GALVANISED FLAT HEAD NAILS.

WALL BRACES.

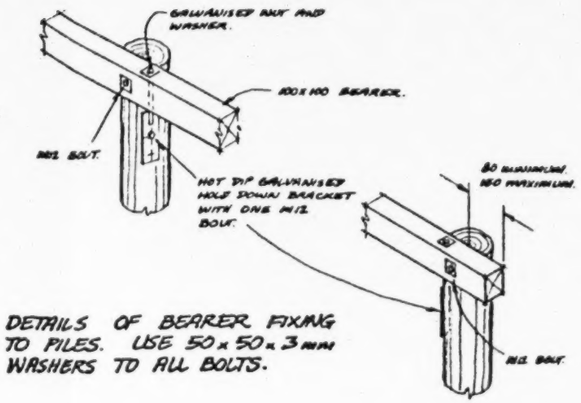
CONSTRUCTION GUIDELINE
FOR SINGLE ROOM DWELLING.



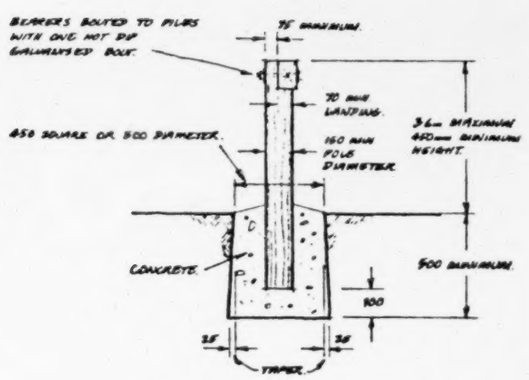
DETAILS OF SUB-FLOOR HOLD DOWN BRACKET. HOT DIP GALVANISE AFTER FABRICATION.


60 EQUAL
60
60
GALVANISED M12 BOLT WITH 50 x 50 x 3 GALVANISED WASHERS.
300
300
100 x 50 SPLICE PLATE SKEW ANVL EACH BEARER END TO PLATE WITH FOUR 100 x 4.5 mm GALVANISED FLAT HEAD NAILS.
TWO HOT DIP GALVANISED HOLD DOWN BRACKETS WITH ONE M12 BOLT PER BRACKET.

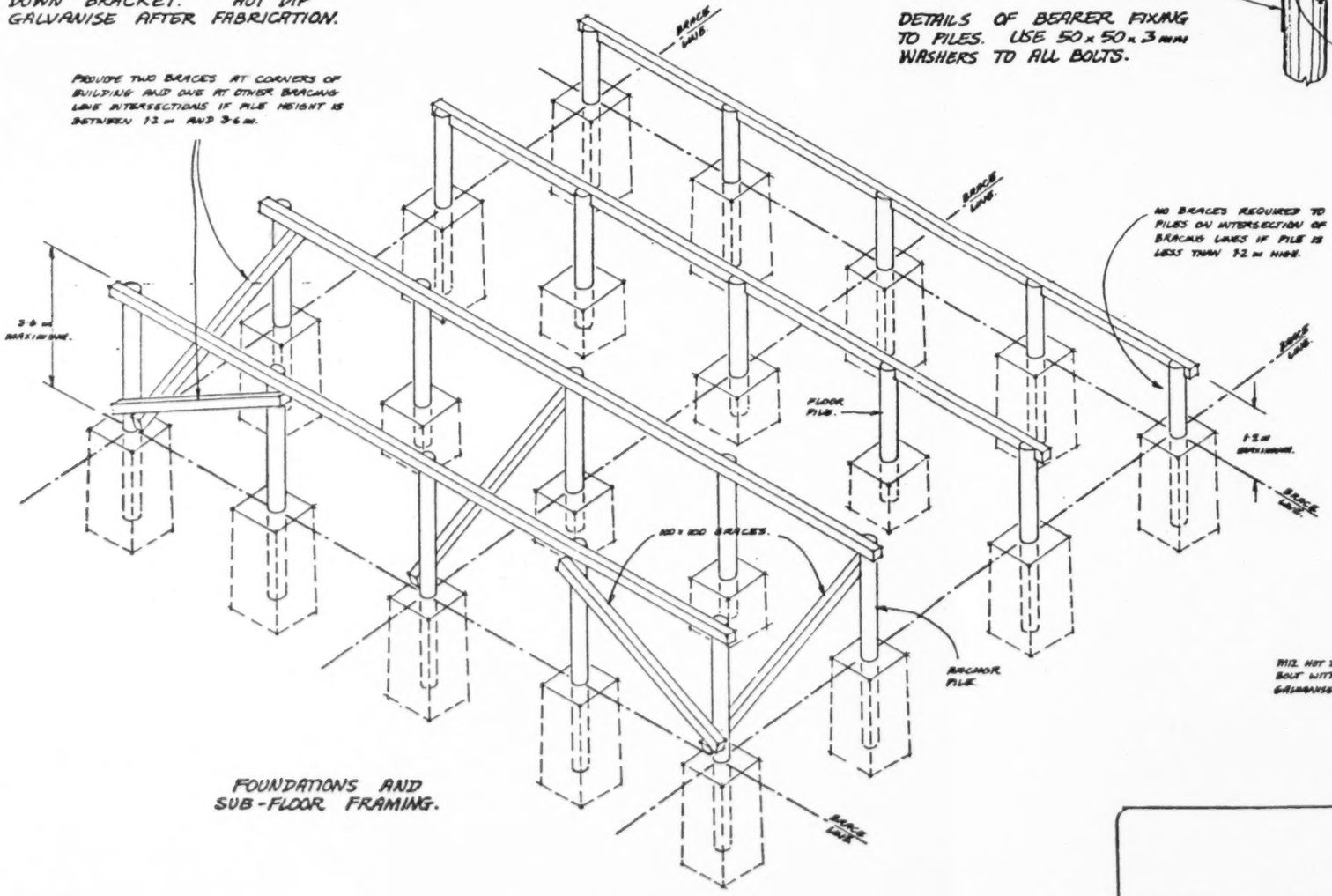
BEARER SPLICE DETAILS.



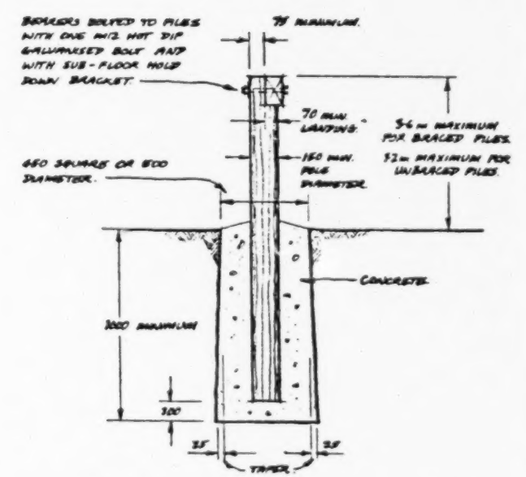
DETAILS OF BEARER FIXING TO PILES. USE 50 x 50 x 3 mm WASHERS TO ALL BOLTS.



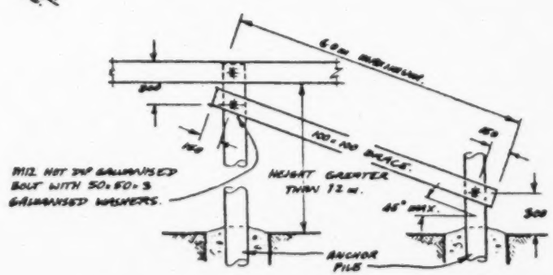
FLOOR PILES TO SUPPORT FLOOR ONLY.


PROVIDE TWO BRACES AT CORNERS OF BUILDING AND ONE AT OTHER BRACING LINE INTERSECTIONS IF PILE HEIGHT IS BETWEEN 1.2 m AND 3.6 m.
BRACE LINE
BRACE LINE
NO BRACES REQUIRED TO PILES ON INTERSECTION OF BRACING LINES IF PILE IS LESS THAN 1.2 m HIGH.
3.6 m MAXIMUM
FLOOR PILE.
1.2 m MINIMUM.
BRACE LINE
100 x 100 BRACES.
ANCHOR PILE.
BRACE LINE

FOUNDATIONS AND SUB-FLOOR FRAMING.



ANCHOR PILES TO SUPPORT ALL LOADBEARING WALLS AND ATTACHED ROOF STRUCTURES.



BRACES TO SUB-FLOOR STRUCTURE.

CONSTRUCTION GUIDELINE
FOR SINGLE ROOM DWELLING.